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The first true atom interferometer was demonstrated. Using transmission gratings as optical elements for atom deBroglie waves, a three grating atom interferometer was constructed which physically separates atom waves before recombining them. This demonstration was closely followed by two demonstrations of atom interometers which used laser light as the beam splitters.

Atom interferometers will make possible qualitatively new types of experiments involving inertial effects, studies of atomic and molecular properties, tests of basic quantum physics, and may ultimately open the way to make ultra-small structures using atom holograms.

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New Developments in Atom Interferometry: Final Report
DAAL03-89-K-0082 (ARO proposal number 26566-PH)

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During this grant period we demonstrated the first true atom interferometer. Using transmission gratings which we fabricated ourselves as optical elements for atom deBroglie waves, we constructed a three grating atom interferometer which physically separates atom waves before recombining them. Our demonstration was closely followed by two demonstrations of atom interferometers which used laser light as the beam splitters.

Atom interferometers will make possible qualitatively new types of experiments involving inertial effects, studies of atomic and molecular properties, tests of basic quantum physics, and may ultimately open the way to make ultra-small structures using atom holograms.

> The relatively large mass and low velocity of atoms makes atom interferometers especially sensitive to inertial effects such as rotation, acceleration, and gravity. Sagnac rotation in accord with theoretical predictions has been observed (4) and sensitivity to gravitational acceleration at the 3×10^{-6} level demonstrated (5). Atom interferometers may become the best absolute accelerometers and gravimeters in the next few years.
>
> Atom interferometers can be applied to a number of experiments in fundamental physics: tests of quantum mechanics such as the Aharonov-Casher effect (6), measurement of the equality of proton and electron charges, and a precise measurement of the momentum of a photon. This latter measurement should produce a new high precision value for the fundamental constants $N_A\hbar$.
>
> Interferometers for atoms and molecules, will offer more accurate ways to measure intrinsic properties of these particles, like their polarizability. They will also open up new areas of study, such as measurements of the "index of refraction" of a gas for a particle beam which passes through it.
>
> The key component of our interferometer is the set of three matched transmision diffraction gratings which we constructed at the National Nanofabrication Facility (NNF) at Cornell University. Our interferometer

consists of three 400 nm period gratings, mounted 0.66m apart on separate translation stages inside the vacuum envelope. During operation, the 0^{th} and 1^{st} order beams from the first grating strike the middle grating (which is 140 μm wide) where they are diffracted in the 1^{st} and -1^{st} orders so that they converge at the third grating. At the second (middle) grating the beams have widths of 30 μm (FWHM) and are separated by 27 μm. The first two gratings form an interference pattern in the plane of the third grating, which acts as a mask to sample this pattern. The detector, located 0.30 m beyond the third grating, records the flux transmitted by the third grating.

The data necessary to determine the interferometer phase contrast are acquired by modulating the position of one grating relative to the other two and simultaneously recording the signal from the atom counting electronics as well as the signal from an optical interferometer used to measure the relative position of the gratings. After removing data obscured by noise spikes from the hot wire, the atom count rate data are averaged into bins according to relative grating position, resulting in a fringe pattern.

The peak to peak amplitude of our interference signal is 70 Hz, which enables us to determine the interferometer phase to a precision of 0.1 rad in 1 min. The excellent long-term stability of our position stabilization system provides measured atom-interferometer phase drift of less than 0.1 rad over 10 min.

In addition to our progress with the atom interferometer, we also devoted effort to the development of new processes to fabricate atom optics as well as their fabrication. Our students made two trips to Cornell University and the NNF to develop and build gratings. The first trip resulted in the development of a new process for fabricating atom optics. The process allows fabrication of precisely positioned openings in thin silicon nitride membranes mounted in silicon frames. The pattern created in the membrane is determined by an electron beam writer, making the process quite versitile. This process was used to create the diffraction gratings used in the interferometer. In addition, several zone plates (atom lenses) were also built, and were later successfully demonstrated. During our second trip we devised ways to reduce the electron beam writing time. This decreased thermal drift during the writing period assuring higher overall accuracy, and also increased our overall productivity. We made a wide variety of diffraction gratings with various heights and periods between 100 and 300 nm, as well as an assortment of single and double slits.

Since the development of the interferometer, we have added a second year graduate student and a visiting postdoctoral fellow to our research team, which now has two graduate students who have finished the two written parts of their qualifiers (one has finished his oral as well). This has enabled us to deal with the experiment on several fronts: we improved the detector and the source, and improved the vacuum system, particularly in the main chamber where the beam used to suffer considerable attenuation. We have also built a septum to place between the two legs of our interferometer. This consists of a mount with a tightly stretched aluminum foil in the middle which extends along the beam axis for 10 cm. It is positioned by a three degree of freedom rotator/translator and we have been able to position it so that its shadow is only 35 microns wide as seen by the atomic beam.

The scientific future of atom interferometers looks bright: atom beam sources are inexpensive and intense relative to other particle beams/sources (eg. neutrons, electrons), several techniques have now been demonstrated to make interferometers for them, and the atoms which may be used in them come with a wide range of parameters such as polarizability, mass, and magnetic moment. This assures the applicability of these instruments to a wide range of measurements of both fundamental and practical interest.

We wrote several papers which were accepted or published, and most science magazines have now written up our pioneering work in atom interferometry.

PUBLICATIONS SUPPORTED BY ARO

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THESES

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